HIGH DENSITY QCD PHYSICS WITH HEAVY IONS IN CMS

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The heavy ion program of the CMS experiment will examine the QCD matter under extreme conditions, through the study of global observables and specific probes.

1 Introduction

The CMS detector has a large acceptance and hermetic coverage. The various subdetectors are: a silicon tracker with pixels and strips ($|\eta| < 2.4$), electromagnetic ($|\eta| < 3$) and hadronic ($|\eta| < 5$) calorimeters, muon chambers ($|\eta| < 2.4$). The acceptance is further extended with forward detectors ($|\eta| < 6.8$). CMS detects leptons and hadrons, both charged and neutral ones. In the following, capabilities in soft, hard and forward physics are described. For a very recent extensive review see Ref. 1.

2 Soft physics

The minimum bias trigger will be based on the requirement of a symmetric number of hits in both forward calorimeters ($3 < |\eta| < 5$, see Fig. 1). For Pb-Pb collisions the centrality trigger will be provided by correlating barrel and forward energies. The charged particle multiplicity can be measured event-by-event using hits in the innermost pixel layer with about 2% accuracy and systematics below 10%.

CMS can study soft physics better than previously thought. Using a modified pixel hit triplet finding algorithm, charged particles down to very low p_T can be reconstructed (Fig. 2-left). Particle identification using energy loss in silicon is possible if $p < 1-2$ GeV/c, benefitting from analogue readout. Acceptances and efficiencies are at 80–90%, the p_T resolution is about 6%. At the same time low fake track rate is achieved thanks to the geometrical shape of the hit cluster: below 10% even in central Pb-Pb for $p_T > 0.4$ GeV/c. This enables the study of

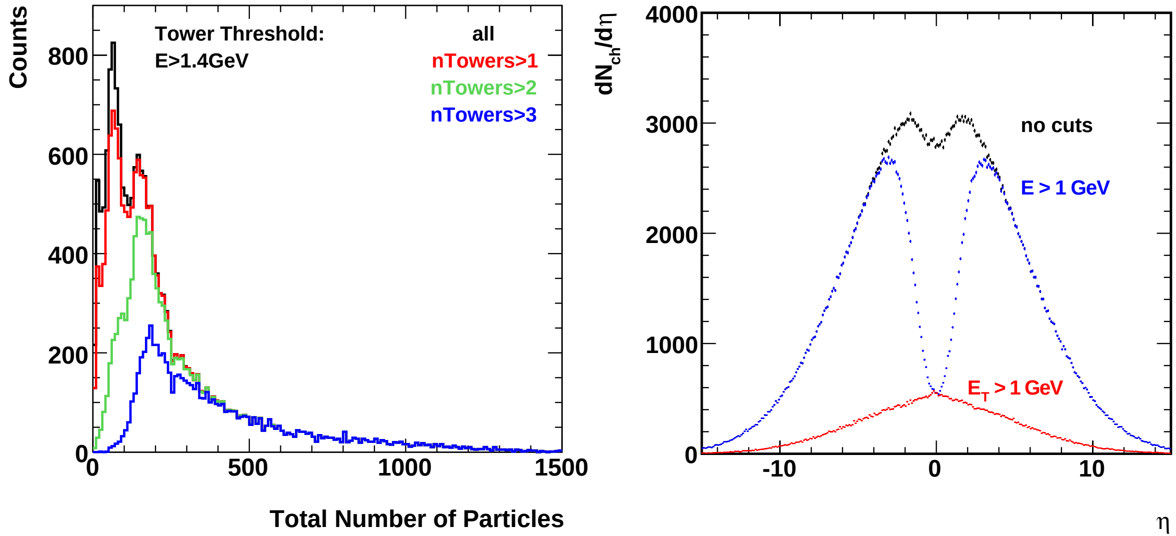

Figure 1: Left: Estimated loss of low multiplicity events due to triggering requirements on nTowers for cuts on E in minimum bias p-p collisions. Right: Pseudo-rapidity distribution of charged hadrons in central Pb-Pb collisions at 5.5 TeV from the Hydjet generator. Particle selection to mimic the level-1 trigger is applied for total $\langle E \rangle$ and transverse $\langle E_T \rangle$ energy.

identified particle spectra (down to p_T of $0.1 - 0.3$ GeV/c) and yields, multiplicity distributions and correlations. Weakly decaying resonances are accessible if the found tracks are combined and selected via decay topology: strange neutral particles ($\mathrm{K^0_S}$, Fig. 2-center, Λ, $\overline{\Lambda}$), multi-strange baryons (Ξ^-, Ω^-). Also open charm (D^0, D^{*+}) and open beauty ($\mathrm{B} \rightarrow \mathrm{J}/\psi + \mathrm{K}$) can be studied.

In Pb-Pb collisions azimuthal correlations give information on the viscosity and parton density of the produced matter. The event plane can be reconstructed using calorimetry. The estimated event plane resolution is about 0.37 rad if $b = 9$ fm. The second moment v_2 can be measured with about 70% accuracy. The results will improve by adding tracker information and using forward detectors, such as the zero degree calorimeter.

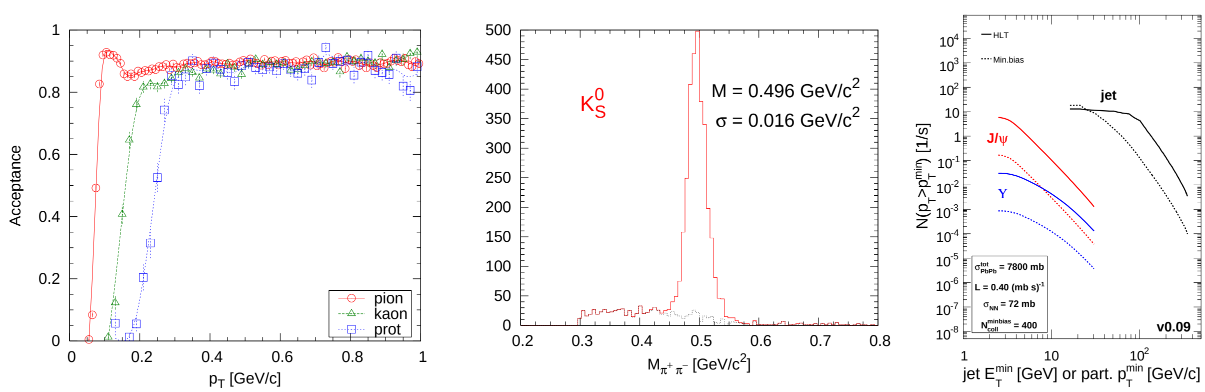

Figure 2: Left: Acceptance of the track reconstruction algorithm as a function of p_T, for tracks in the range $|\eta| < 1$. Values are given separately for pions (circles), kaons (triangles) and (anti)protons (squares). Center: Invariant mass distribution of reconstructed $\mathrm{K^0_S} \rightarrow \pi^+\pi^-$ in single minimum bias p-p collisions. The mass distribution of the background is indicated with a black dashed histogram. Right: Minimum bias and high level trigger J/ψ, Υ, and jet trigger rates for design luminosity in central Pb-Pb collisions.

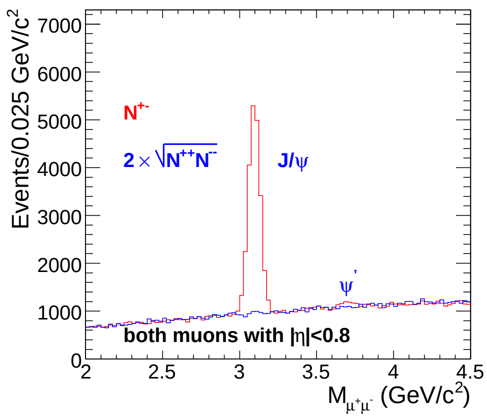

Figure 3: (color online) Invariant mass spectra of opposite-sign and like-sign muon pairs with $\mathrm{d}N_{ch}/\mathrm{d}\eta|_{\eta=0} = 2500$, in the J/$\psi$ (left) and Υ (right) mass regions.

3 Hard physics

Interesting events are selected first by the level-1 trigger. It is a fast hardware trigger, decisions are made within about 3 μs after the collision. It mostly uses signals from the muon chambers and calorimeters. After that step the event rate is still high, the efficient observation of rare hard probes requires a high level trigger (HLT). The trigger uses about ten thousand CPUs working with the full event information including data from the silicon tracker. A detailed study has been done with running offline algorithms by parametrising their performance. Trigger tables are produced considering various channels and luminosity scenarios (Fig. 2-right).

Charmonium and bottomonium resonances can report on the thermodynamical state of the medium via their melting. It is an open question whether they are regenerated or suppressed at LHC energy. They can be reconstructed in the dimuon decay channel with help of precise tracking. Acceptances are at 25% (Υ) and 1.2% (J/ψ) with 80% efficiency and 90% purity. The mass resolution is 86 MeV/c^2 at the Υ mass and 35 MeV/c^2 at the J/ψ mass, in the full acceptance, and even better in the barrel (Fig. 3). This is the best resolution achieved at the LHC. With help of the HLT, 50 times more J/ψ and 10 times more Υ will be collected.

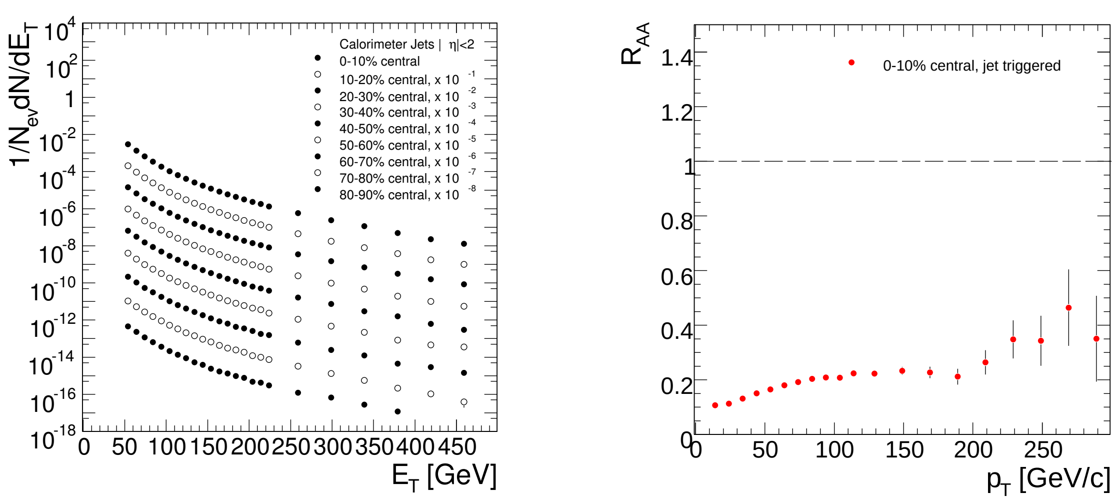

Figure 4: Left: Expected inclusive jet E_T distributions in 10 centrality bins. Right: Expected statistical reach for the nuclear modification factor for inclusive charged hadrons. For both figures, central Pb-Pb collisions at 5.5 TeV have been generated by Hydjet, with integrated luminosity of 0.5 nb^{-1}.

Finding jets on top of a high background is a challenge in Pb-Pb collisions. Jets are reconstructed using a pile-up subtraction algorithm. It consists of an iterative jet cone finder and an event-by-event background subtraction. For 100 GeV jets the directional resolutions are $\sigma_\eta \approx 2.8\%$, $\sigma_\phi \approx 3.2\%$, while the energy resolution is $\sigma_{E_T} \approx 16\%$. Thanks to the HLT, the reach of the jet E_T measurement can be extended to about 0.5 TeV (Fig. 4-left). The data sets, triggered with 50, 75 and 100 GeV, are merged with a simple scaling procedure.

Parton energy loss in the hot and dense medium created in Pb-Pb collisions can be studied by measuring the nuclear modification factors R_{AA} and R_{CP}. High p_T charged particles can be tracked with about 75% algorithmic efficiency, few percent fake track rate for $p_T > 1$ GeV/c and excellent momentum resolution. Using the HLT, the p_T reach of the measurement is extended from 90 to 300 GeV/c (Fig. 4-right).

4 Forward physics

The study of diffractive photoproduction of vector mesons in ultraperipheral Pb-Pb collisions can constrain the gluon density at small x (Fig. 5-left). The decay channels $\rho \to \pi^+\pi^-$ and $\Upsilon \to \mathrm{e}^+\mathrm{e}^-$ or $\mu^+\mu^-$ have been studied, tagged with forward neutron detection in the zero degree calorimeter. The combined acceptance and efficiency of the method is around 20% and it gives a good mass resolution in both channels (Fig. 5-centre and right).

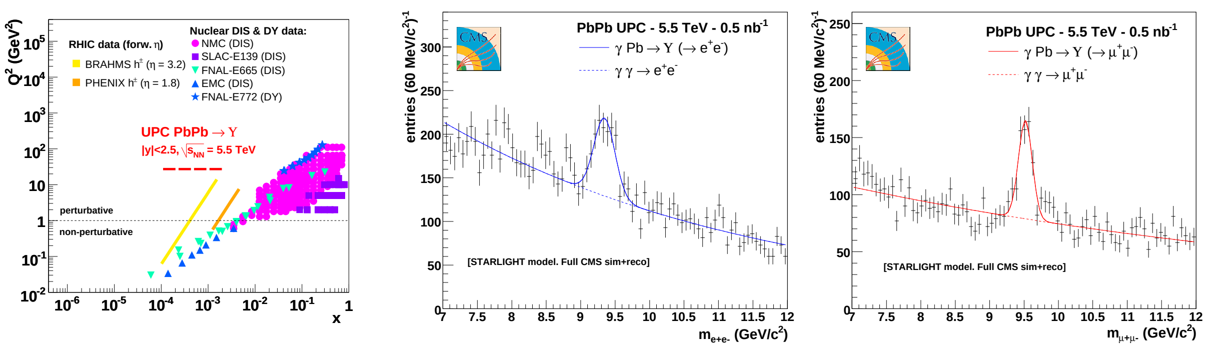

Figure 5: Left: The approximate (x, Q^2) range covered by photoproduction in ultraperipheral Pb-Pb collisions at the LHC is indicated. Right: Invariant mass $\mathrm{e}^+\mathrm{e}^-$ and $\mu^+\mu^-$ distributions for photoproduced Υ and dilepton continuum, as expected in ultraperipheral Pb-Pb collisions at 5.5 TeV, for integrated luminosity of 0.5 nb^{-1}.

5 Summary

The CMS detector combines capabilities for global event characterization and for physics with specific probes. It performs equally well in soft, hard and in forward physics, often supported by high level triggering.

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References

1. CMS Collaboration, *"CMS Physics: Technical Design Report vol. 2. Addendum on High Density QCD with Heavy Ions,"* CERN-LHCC-2007-009.